A Compact Conformal End-Fire Antenna for 60 GHz Wireless Applications

Arnaud L. Amadjikpè* (1), Debabani Choudhury (2), George E. Ponchak (3) and John Papapolymerou (1)
(1) Georgia Institute of Technology, Atlanta, GA, 30308
(2) Intel Corporation, Hillsboro, OR, 97124
(3) NASA Glenn Research Center, Cleveland, OH, 44135
E-mail: arnaud.amadjikpe@gatech.edu

Introduction

The 60 GHz unlicensed spectrum (56 GHz to 66 GHz) has received a lot of attention over the last couple of years for enabling over 1 Gbps high speed wireless communications. The propagation characteristics of this unlicensed frequency band is extreme because of the high atmospheric absorption (~10 dB/km at the sea level). These conditions require highly directive and high gain antennas at both the transmitter and the receiver to maximize the wireless communication throughput. End-Fire antennas [1]-[3] are very good candidates for such applications.
In this paper, a linearly tapered slot antenna (LTSA) with a small form-factor ($2\lambda_0 \times \lambda_0$) is designed on liquid crystal polymer (LCP), - a flexible, light weight, low loss and low cost organic substrate [4]. Taking advantage of the LCP flexibility, the designed LTSA can conform to the surface of commonly commercialized portable wireless devices. A prototype of the designed LTSA is fabricated and measured in both flat and conformed configurations.

Antenna design

The Linearly Tapered Slot Antenna (LTSA) is designed on an 8 mil thick LCP dielectric substrate ($\varepsilon_r = 3.16$, $\tan\delta = 0.004$ at 60 GHz [4]).The LTSA is patterned on the top side of the dielectric with a 3 um thick copper layer (Fig. 1a). The antenna is fed from the back, with a 50 Ω microstrip line patterned on the bottom side of the dielectric. The magnetic field surrounding the microstrip line couples easily to the magnetic field inside the slotline, such that a good microstrip-to-slotline transition is obtained [5]. The microstrip end is terminated with a circular stub for wider bandwidth characteristics [6]. The slot is tapered appropriately, such that the characteristic impedance of the slot at the open end is about 377 Ω, to provide good impedance matching and ensure proper radiation into the air. The overall antenna size is 10 mm × 5 mm (or $2\lambda_0 \times \lambda_0$ at 60 GHz). A detailed description of the antenna dimensions is given in Fig. 1b. Fig. 2 presents a photograph of the fabricated antenna on the LCP substrate.

Simulation and measurement results

Fig. 3 shows the simulated [7] and measured return loss of the flat LTSA. The two plots are in good agreement. In simulation, a resonance occurs at 61.6 GHz

978-1-4244-3647-7/09/$25.00 ©2009 IEEE

and the bandwidth is about 5 GHz. In the measurements, a resonance appears around 62 GHz and the bandwidth is about 5.6 GHz. The flat antenna peak gain increases with frequency in both simulation and measurement, as expected for TSAs (Fig. 4). The anomalous drop in the measured peak gain, at 64 GHz, is probably caused by a small measurement error. The measured peak gain varies between 9.22 dBi and 9.98 dBi, and is about 0.5 dB higher than the simulated one. A comparison of the simulated and measured half-power beamwidth (3dB BW) gives an explanation to this. As shown in Fig. 5, the measured E-plane 3 dB beamwidth is about 5° less than the simulated one. The measured H-plane 3 dB beamwidth is about 12° less than the simulated value. As the measured beam is narrower than the simulated beam, the measured peak gain gets higher. Fig. 5 also shows that the 3 dB beamwidth decreases with frequency.

The E-plane ($\Theta = 90°$) normalized radiation pattern at 62 GHz is plotted in Fig. 6a. The antenna pattern is scanned from $\Phi = 0°$ to $\Phi = 180°$, with $\Phi = 90°$ representing the end-fire direction. The second half of the radiation pattern is not measured because of the mechanical limitations of the measurement tool. The minor asymmetry in both simulated and measured patterns is caused by the feeding line. The side lobe at $\Phi = 170°$ is about 6 dB higher than in simulation. Again, as the measured beamwidth is less than the simulated one, some part of the energy is radiated in the direction of the side lobe. The measured cross-polarized level is at least 11.95 dB less than the peak gain compared to the simulated value of 16.67 dB.

Fig. 6b shows the normalized radiation pattern in the H-plane ($\Phi = 90°$). The antenna pattern is scanned from $\Theta = 0°$ to $\Theta = 180°$, with $\Theta = 90°$ representing the end-fire direction. The measured pattern shows a null at $\Theta = 134°$ whereas the corresponding simulated null appears at $\Theta = 162°$. The narrower measured beam explains the high side lobe (~1.26 dBi) at $\Theta = 160°$. The measured cross-polarized level is at least 12.95 dB less than the peak gain compared to the simulated value of 20 dB.

The LTSA is finally conformed such as to have a curvature radius of 19 mm (Fig.1a). This step is carried out to evaluate the performance of the antenna when it is conformed to a curved surface for mobile platform insertion. The H-plane pattern of the conformed antenna rotates by about 18° in the direction through which it is curved (Fig. 7). The conformed LTSA has a 7.48 dBi peak gain, that is, 2.5 dB less than the flat antenna. These observations indicate that wrapping the LTSA for mounting on a mobile platform plastic chassis will direct the beam toward the curving direction, with a slight peak gain drop.

Conclusion

We demonstrated an end-fire linearly tapered slot antenna with a very small form-factor ($2\lambda_0 \times \lambda_0$), a 5.6 GHz measured bandwidth and a 9.98 dBi measured peak gain, designed on LCP substrate for 60 GHz wireless applications. When this antenna is conformed to a curved surface, the beam is tilted toward the direction in which it is curved. Wrapping the LTSA also decreases the peak gain by about

2.5 dB. Overall, this conformal antenna exhibits very encouraging performance and should suit well for 60GHz wireless applications.

References

[1] K. W. Kim, Y. Rahmat-Samii, "Handset antennas and humans at Ka-band: the importance of directional antennas," *IEEE Transactions on Antennas and Propagation,* Vol. 46, No. 6, pp. 949-950, June 1998.

[2] H. Oraizi, S. Jam, "Optimum Design of Tapered Slot Antenna Profile," *IEEE Transactions on Antennas and Propagation,* Vol. 51, No. 8, pp. 1987-1995, August 2003.

[3] R. Janaswamy, D. H. Schaubert, "Analysis of the Tapered Slot Antenna," *IEEE Transactions on Antennas and Propagation,* Vol. 35, No. 9, pp. 1058-1065, September 1987.

[4] D. Thompson, O. Tantot, H. Jallageas, G. Ponchak, M. Tentzeris and J. Papapolymerou, "Characterization of Liquid Crystal Polymer (LCP) Material and Transmission Lines on LCP Substrates From 30-110 GHz," *IEEE Transactions on Microwave Theory and Techniques,* Vol. 52, No. 4, pp. 1343-1352, April 2004.

[5] K. C. Gupta, R. Garg, I. Bahl, P. Bhartia *Microstrip Lines and Slotlines* Nordwood, MA: Artech House, 1996, pp. 305.

[6] K. C. Gupta, R. Garg, I. Bahl, P. Bhartia *Microstrip Lines and Slotlines* Nordwood, MA: Artech House, 1996, pp. 312.

[7] http://www.ansoft.com/HFSS/

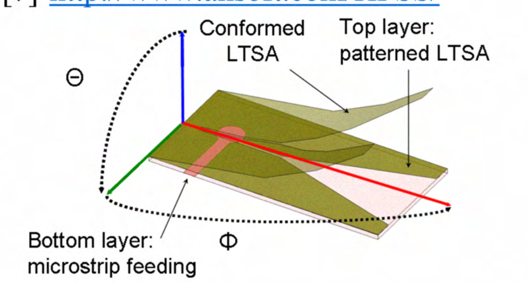

Fig. 1a. 3D view of the designed LTSA.

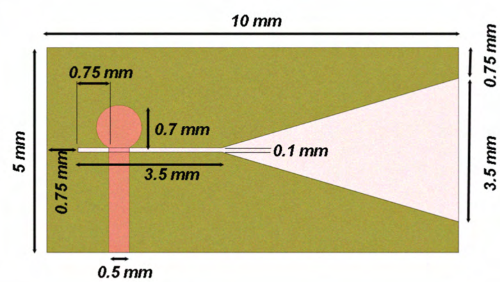

Fig. 1b. Top view of the LTSA.

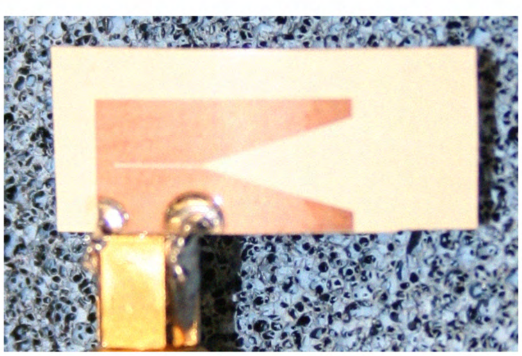

Fig. 2. Photograph of the fabricated LTSA.

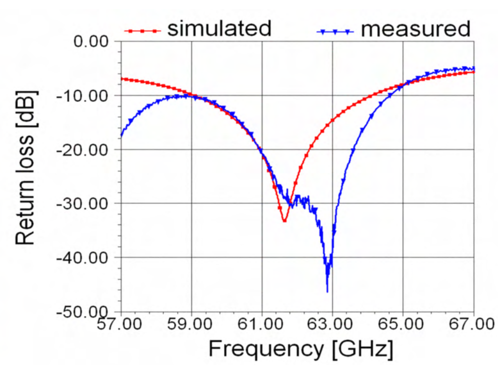

Fig. 3. Simulated and measured return loss of the flat LTSA.

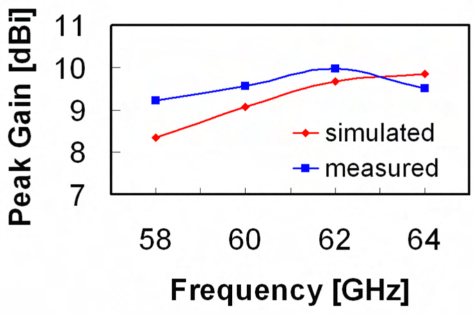

Fig. 4. Peak gain of the flat LTSA as a function of frequency.

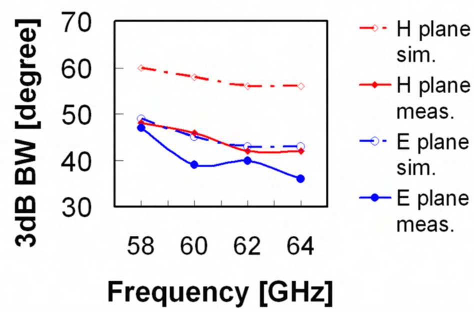

Fig. 5. Simulated and measured H and E-plane 3 dB beamwidth of the flat LTSA.

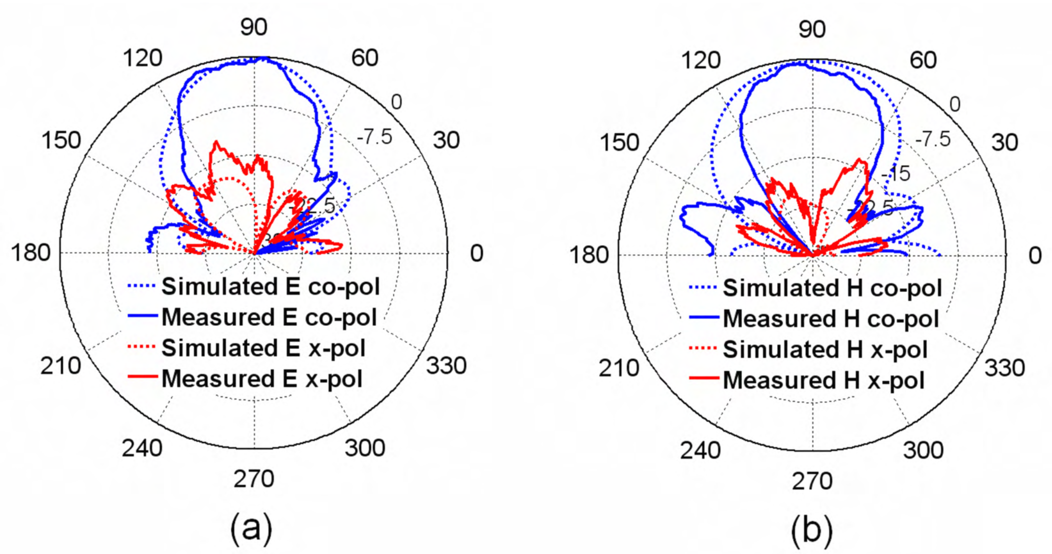

Fig. 6. Normalized radiation pattern of the flat LTSA at 62 GHz: (a) E-plane (b) H-plane.

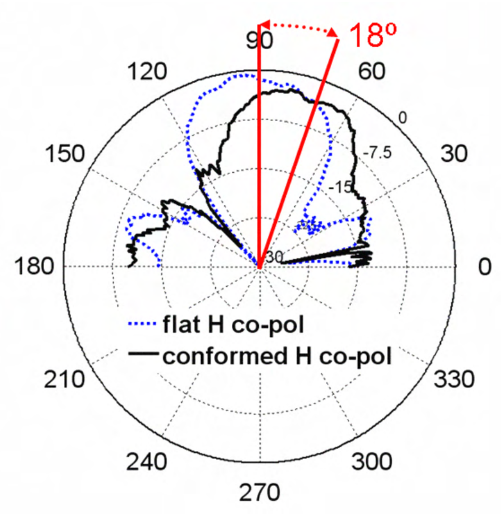

Fig. 7. Normalized H-plane patterns at 62 GHz: flat and conformed LTSA.